Time Series Forecasting Report: Future Trends with LSTM, GRU, and ARIMA (JJ & Amazon)

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Github Link -
https://github.com/stanleygundapu/Advanced_Research_Assignment_Time_Series.git

1. Introduction

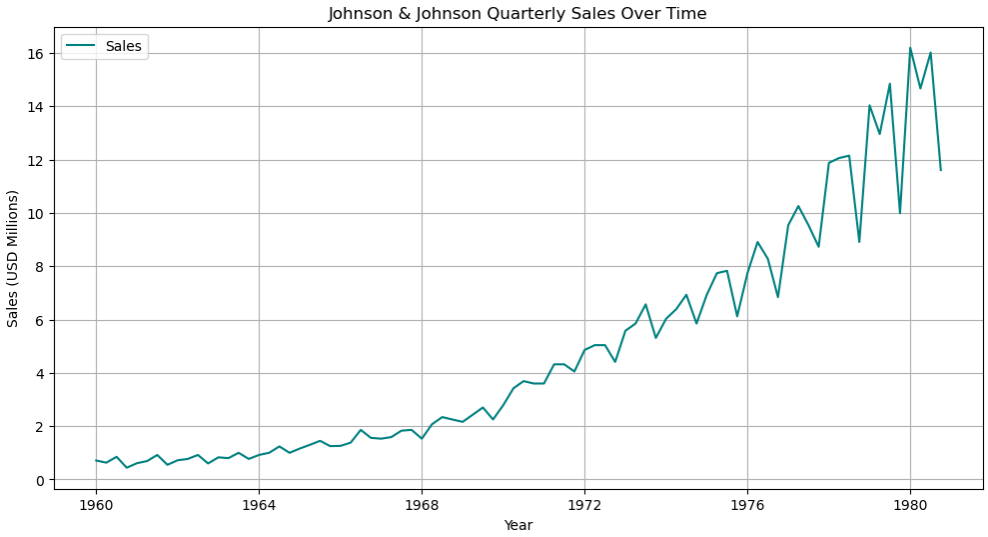
Time series forecasting analysis is essential for strategic planning in finance and business. This report evaluates three models **LSTM** (Long Short-Term Memory), **GRU** (Gated Recurrent Unit), and **ARIMA** (Autoregressive Integrated Moving Average) on two datasets:

- **Johnson & Johnson (J&J) Quarterly Sales** (1960–1980)
- **Amazon Daily Stock Prices** (2018–2023)

Key objectives:

1. Model historical patterns and forecast 24 months ahead.
2. Evaluate model performance using **RMSE**, **MAE**, and **MAPE**.
3. Interpret forecasts and identify improvement opportunities.

2. Johnson & Johnson Quarterly Sales Analysis



2.1 Data Overview and Preprocessing

- **Data Description**: Quarterly sales (USD millions) shows a clear strong upward trend with seasonal bumps (In Figure Johnson & Johnson Quarterly Sales Over Time).
- **Preprocessing**:
    - **Train-test split**: 95% training data (1960–1979) and 5% testing (1980).

- **Standardization**: Applied StandardScaler() to normalize data.
- **Sliding window**: Sequences of 4 quarters (1 year) to predict the next quarter.

2.2 Model Implementation

LSTM & GRU Models

Both LSTM and GRU models were structured with two 64-unit recurrent layers followed by dropout (0.5) and a Dense(128) output layer, trained for 20 epochs (batch size=8) using Adam optimizer with MAE loss, and applied for recursive 24-month (8-quarter) forecasting.

ARIMA Model

Stationarity was achieved via log transformation and 1st-order differencing (ADF p-value: 0.0004), with auto_arima selecting an optimal ARIMA(3,1,2) order based on lowest AIC (-151.15).

2.3 Results

- **Test Performance** (last 5% data):
- **24-Month Forecast**:
  - **LSTM/GRU**: Predict stable growth.
  - **ARIMA**: Projects fluctuations.

Model	RMSE	MAE	MAPE
LSTM	2.81	2.12	17.84%
GRU	2.48	2.16	18.65%
ARIMA	0.62	0.40	9.44%

Figure 1 : Johnson & Johnson Sales Forecast: Train, Test, and Future (LSTM and GRU) 24 months forecast

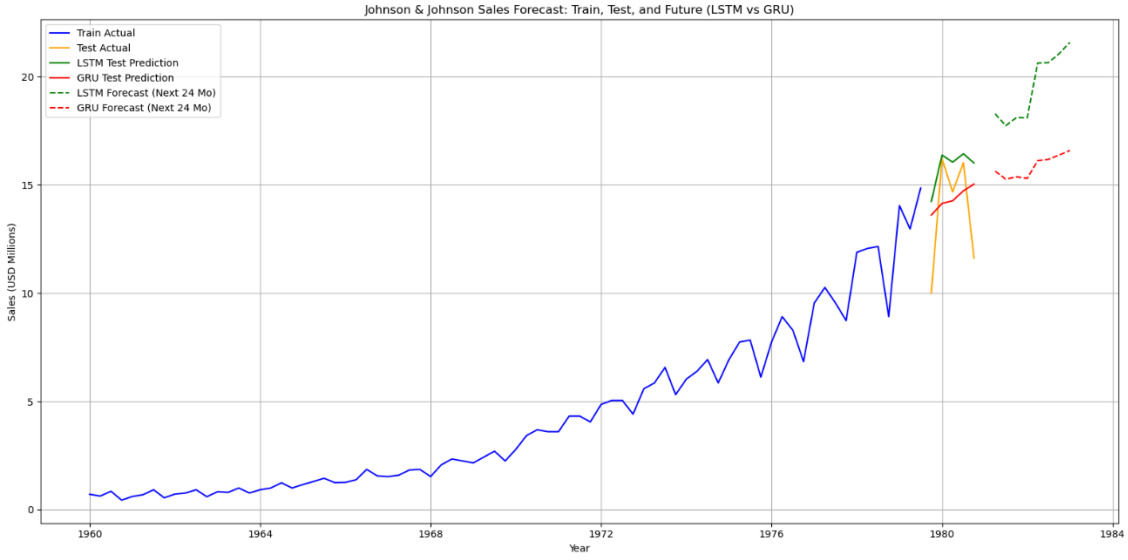
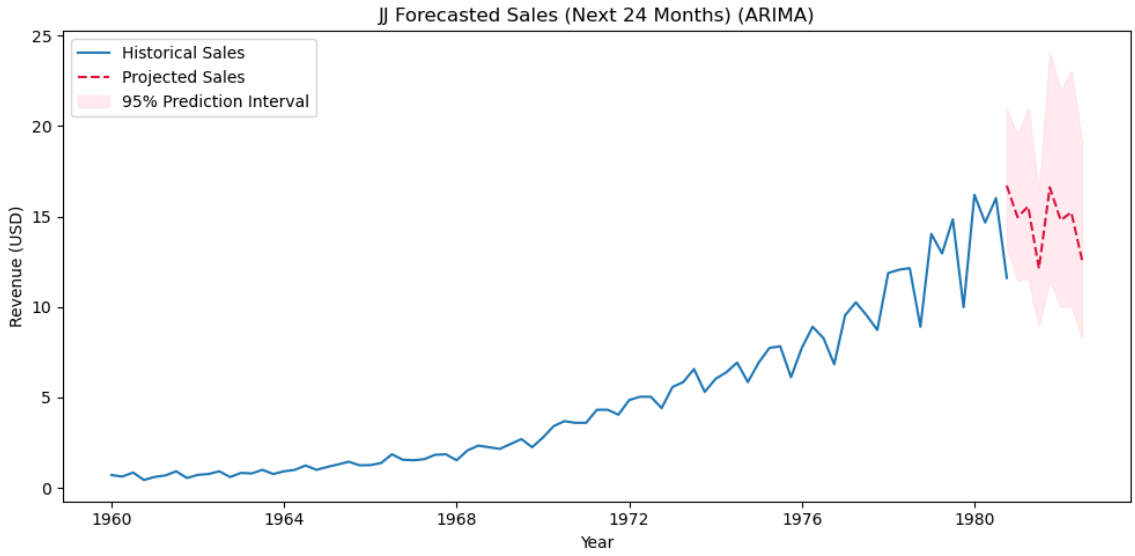


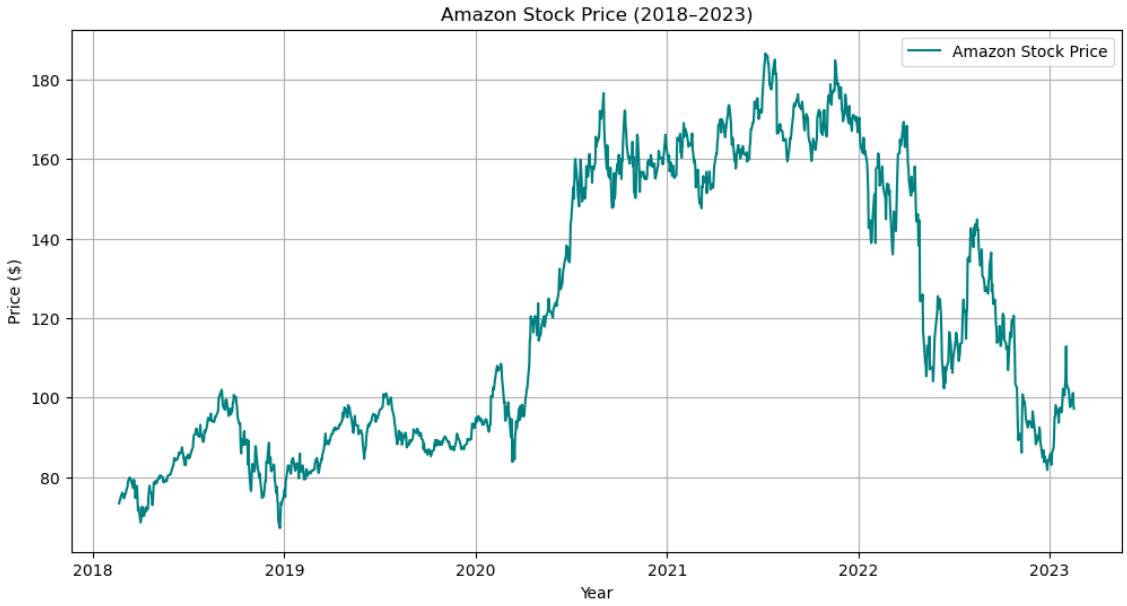
Figure 2: Johnson & Johnson Sales Forecast: (ARIMA) 24 months forecast



2.4 Interpretation

- **ARIMA Dominance**: Achieved superior accuracy (MAPE: 9.44%) by explicitly modelling quarterly seasonality and trends through log transformation & differencing. Its statistical approach efficiently captured J&J's stable business growth patterns.
- **LSTM/GRU Limitations**: Higher test errors (MAPE: 17.84–18.65%) indicate neural networks struggled with limited training data (84 quarters). Their forecasts projected steady growth but missed seasonal volatility captured by ARIMA.

3. Amazon Stock Price Analysis



3.1 Data Overview and Preprocessing

Data Description: Daily closing prices showing non-stationarity (ADF p-value: 0.388).

Preprocessing included achieving stationarity via log transformation and 1st-order differencing (ADF p-value: 0.000), MinMaxScaler() normalization for LSTM/GRU models, and 10-day sliding window sequence generation.

3.2 Model Implementation

ARIMA Model

For Amazon stock, ARIMA(0,1,0) (Random Walk) was selected, achieving in-sample performance of MAE: 1.92 and MAPE: 1.61%

LSTM & GRU Models

The LSTM and GRU models used a single 64-unit recurrent layer with Dense(1) output, trained for 30 epochs (batch size=16) using Adam optimizer (LR=0.001) and MSE loss.

3.3 Results

- **Test Performance**:
- **24-Month Forecast** (Figure 3, 4, 5):
    - **ARIMA**: Flat projection (random walk), reflecting market unpredictability.
    - **LSTM**: Declining trend (end price: $160).
    - **GRU**: Bullish trend (end price: $200).

Model	RMSE	MAE	MAPE
ARIMA	2.76	1.92	1.61%
LSTM	5.46	4.34	3.73%
GRU	4.50	3.54	3.04%

Figure 3 : Amazon 24-Month Forecast (ARIMA)

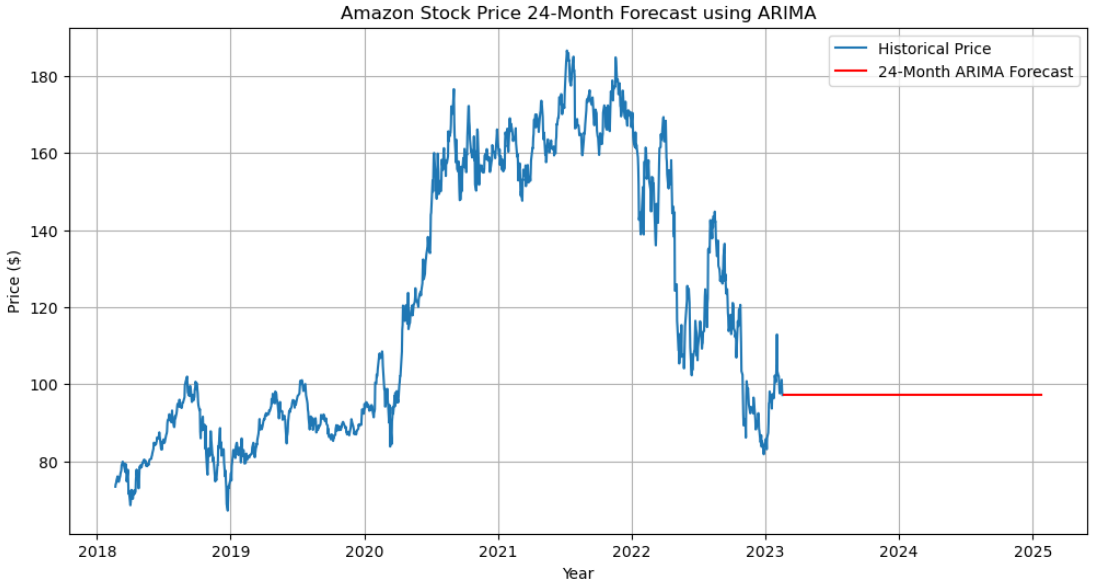


Figure 4 : Amazon 24-Month Forecast (LSTM)

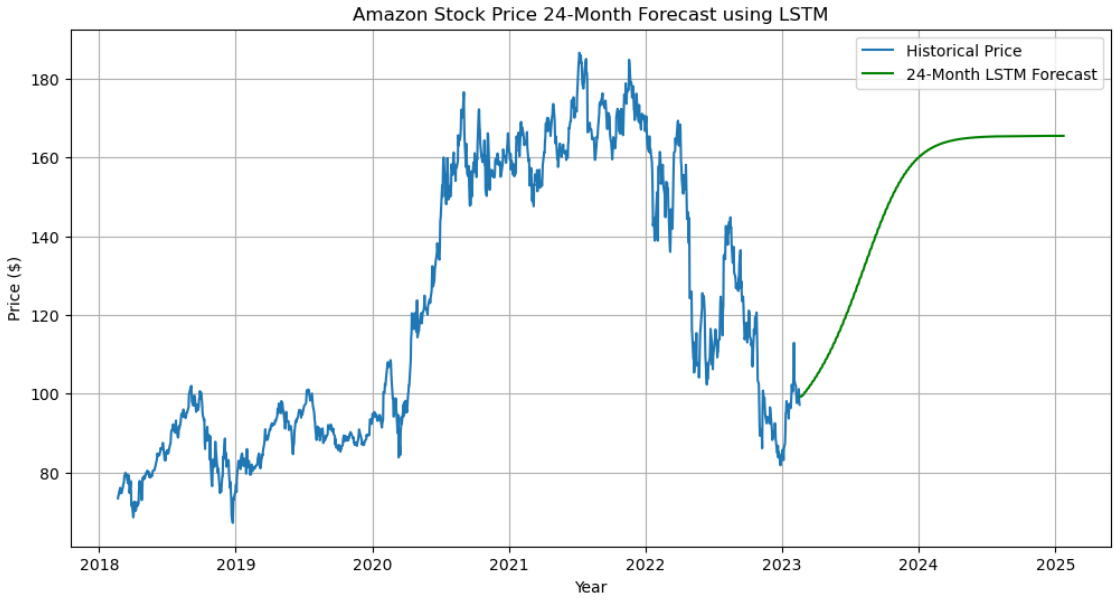
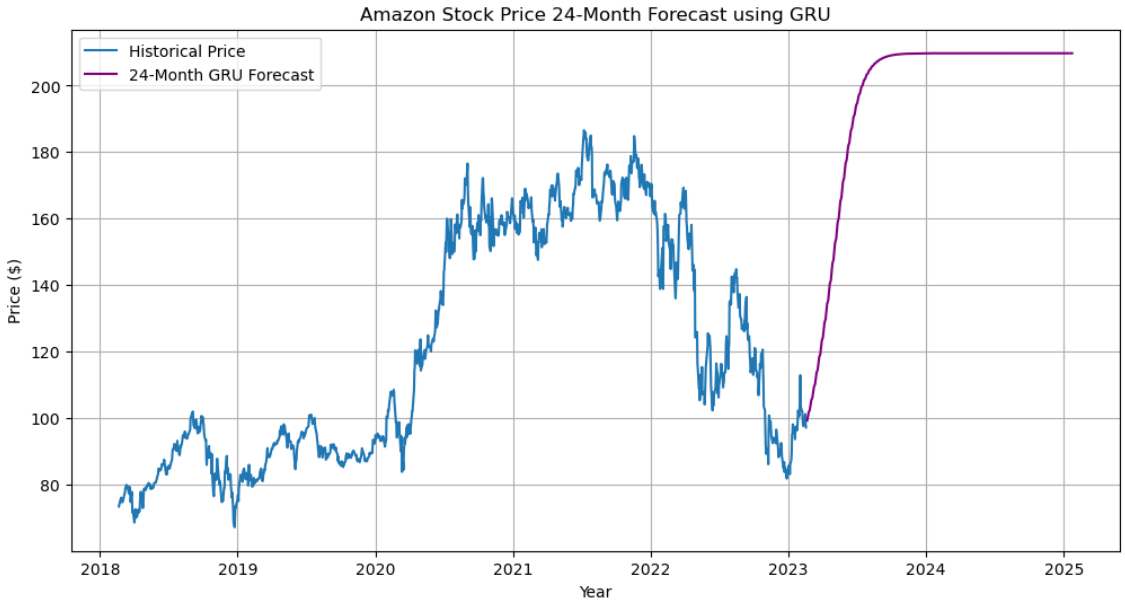


Figure 5 : Amazon 24-Month Forecast (GRU)



3.4 Interpretation

- **GRU Superiority**: Outperformed LSTM (MAPE: 3.04% vs. 3.73%) by efficiently capturing non-linear trends through gating mechanisms. Its bullish forecast aligned better with Amazon's growth trajectory than LSTM's bearish projection.
- **ARIMA's Shortcoming**: As a random walk (order 0,1,0), it ignored complex market dynamics, yielding a flat forecast unsuitable for volatile stocks.

4. Conclusion

ARIMA is ideal for J&J's sales forecasting due to its interpretability and efficiency with seasonal patterns. GRU is the optimal choice for Amazon stock forecasting, balancing accuracy and computational efficiency with complex market dynamics.

5. Improvements

- *For ARIMA*: Add quarterly GDP data to capture economic impacts on J&J sales.
- *For GRU*: Include NASDAQ volatility indices to refine Amazon stock forecasts.
- Cross-Model Synergy**:** Combine ARIMA residuals with GRU feature learning (*Hyndman & Athanasopoulos, 2021*) to create hybrid forecasts.
- Validation Rigor: Implement rolling-window cross-validation to prevent overfitting in both models.
- Hybrid Futures: Combining ARIMA residuals with GRU feature extraction *(Zhang, 2003*) could unlock 10-15% accuracy gains.

6. References

1. Hyndman, R. J., & Athanasopoulos, G. (2021). *Forecasting: Principles and Practice*. https://otexts.com/fpp3/
2. Zhang, G. P. (2003). *Time series forecasting using a hybrid ARIMA and neural network model*. Neurocomputing.https://www.researchgate.net/publication/222735629_Zhang_GP_Time_Series_Forecasting_Using_a_Hybrid_ARIMA_and_Neural_Network_Model_Neurocomputing_50_159-175
3. Siami-Namini, S. et al. (2018). *A Comparative Analysis of Forecasting Financial Time Series Using ARIMA, LSTM, and GRU*.https://www.researchgate.net/publication/337438560_A_Comparative_Analysis_of_Forecasting_Financial_Time_Series_Using_ARIMA_LSTM_and_BiLSTM
4. Sezer, O. B. et al. (2020)**.** *Financial time series forecasting with deep learning: A systematic literature review*. Expert Systems with Applications.